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Biomass as energy source in Brazil

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Abstract

The objective of this paper is to give an overview of the programs, projects and technologies related to the use of biofuels in Brazil. An evaluation of the biomass availability and electricity generation potential for different industrial and agricultural sectors is also presented. As a result an estimation of the overall technical potential for electricity generation based on biofuels in Brazil is presented as well. In addition, the state-of-the-art of different biomass electricity conversing technologies is discussed. A diagram is presented about the organization links and funding of biomass energy research activities in Brazil. Main development and research activities being carried out in this area at the Excellence Group in Thermal Power and Distributed Generation - NEST at the Mechanical Engineering Institute of the Federal University of Itajubá - UNIFEI, located in the city of Itajubá, Brazil are presented.

Keywords: Biomass availability; Electricity generation; Research and development projects; Biomass potential in Brazil

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1. Introduction

Biofuels could be one of the solutions for electric power supply in Amazonian region isolated communities and for development programs in rural areas. For that, there must be appropriate technology base and sustainable management models. Today, however, there are no highly reliable commercial technologies available for small-scaled power generation out of biomass that presents low investment costs and easy O&M.

Another important aspect of bioenergy is its potential contribution towards the solution of environmental problems caused by the use of fossil fuels. The mitigation of the greenhouse effect is possible through the sustainable use of biomass as fuel and/or the sequestration of the atmospheric carbon by the forests. This way, Kyoto's Protocol allows the emission and commercialization of carbon credits by means of implementing bioenergy projects, and more recently, by means of reforestation activities. In addition the direct replacement of fossil fuels for biomass leads to a considerable reduction in the emissions of sulfur and nitrogen oxides.

The objective of this paper is to show an overview of the available potential and technologies related to the implementation of bioenergy in Brazil. A diagram about the organization and funding of biomass energy research actions activities in Brazil is presented. An assessment of the main ongoing projects was also included, as well as a summary of the R&D activities that are currently being carried out by NEST - Excellence Group in Thermal and Distributed Generation at the Federal University of Itajubá located in the south of the state of Minas Gerais, Brazil.

2. Biomass in the Brazilian energy balance

The internal offer of energy in Brazil in 2006 (Figs. 1 and 2) was 226 million of toe (tonnes of oil equivalent) or 1.12 toe per inhabitant. Renewable sources of energy were responsible for 45.1% of this amount, where 14.8% came from hydro sources and 27.2% from biomass.

The production of alcohol within this period reached 17.76 million cubic meters [1]. The figures forecast for 2022 estimate a production of 23.7 million [2].

The production of electricity out of biomass in Brazil in 2006 corresponded to approximately 4.4% of the total generated amount, which was 419.3 TWh. Out of sugar cane bagasse 8.35 TWh were generated, 0.72 TWh out of firewood, 5.19 TWh out of black liquor and 4.25 TWh out of agricultural residues [1].

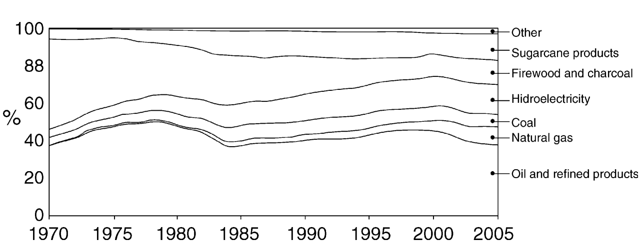


Fig. 1. Evolution of the internal energy offer composition within the period between 1970 and 2005 [1].

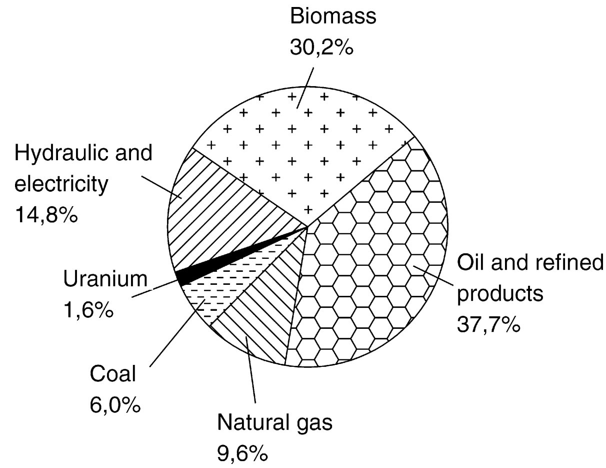


Fig. 2. Internal energy offer in Brazil in the year of 2006 [1].

The total installed power is 96.63 GW from which 4.74 GW corresponds to biomass, that is, 4.9% [3]. Six thermal power plants using biomass are being built and their installed power is 80.35 MW. Also, the construction of 42 other units comprising a total power of 673.6 MW has already been authorized [3].

It is possible to observe that a transition process has been taking place. It started at a low technological level known as 'conventional biomass', which includes, for example, the use of firewood for cooking food, and it is going to 'modern biomass', which is related to the use of biomass for generating industrial heat and electricity and the production of fuels. Fig. 3 shows that the fraction of modern biomass in the Brazilian energy matrix (11.3%) is practically the same as traditional biomass (12.5%) [4]. In a global scale the situation is very different as modern biomass corresponds to 4 only 1.73% of the whole energy consumption.

In Brazil, the implementation of bioenergy is taking place at three levels, which are: a first level at low powers ranging from 1 to 3 to a few dozens of kWs (typical of small communities); a second level characterized by powers reaching up to some MWs, which is typical of communities with hundreds of inhabitants, saw-mills, furniture factories and rice treatment plants; and there is a third level presenting powers over 5–10 MW, typical of sugar and alcohol plants, cellulose and paper factories and biomass thermal power plants as well.

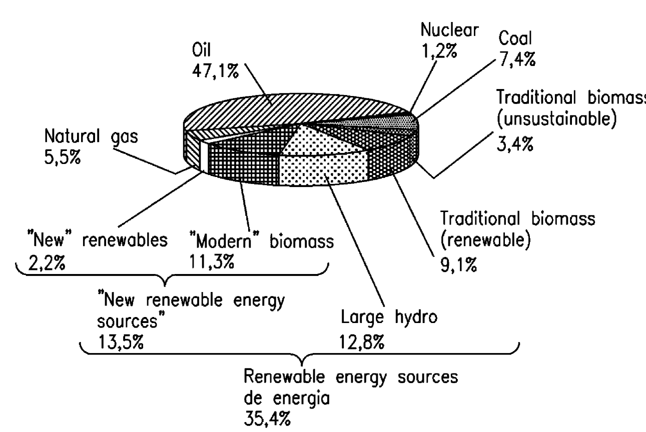


Fig. 3. Modern and traditional biomass use in Brazil [4].

3. Biomass energy potential estimation in Brazil

3.1. Sugar and alcohol sector

There are 325 sugar/alcohol industries in Brazil. They process 426.6 million tonnes of sugar cane every year, generating 121.15 million tonnes of bagasse [5]. Each tonne of sugar cane produces an average of 140 kg of bagasse, 150 kg of sugar and 140 kg of straw (sugar cane agricultural residue). All of the thermal power and 95% of the electricity consumed by sugar industries (1.48 GW) are generated out of sugar cane bagasse. Considering the case of ethanol, the obtained energy is 8–9 times as great as the energy consumed in the agricultural and industrial stages, which makes it extremely attractive if compared with other kinds of renewable sources throughout the world. Besides, the production of alcohol in Brazil causes a reduction in the emission of greenhouse gases ranging about 12.7 million tonnes of equivalent carbon [6] with a productivity of 6350.0 L of alcohol per hectare [5].

The technical potential for the generation of electricity in the sugar/alcohol sector using high-parameter steam cycles is 3.85 GW using 40% of existing cane straw [7]. Other studies mention a variation from 6 to 8 GW. The highest values are attained by considering BIG-GT technology (Biomass Integrated Gasification-Gas Turbine), which integrates the sugar cane bagasse gasification with gas turbines in a combined cycle.

In the sugar and alcohol sector in 2002 there were 619 MW available for the electric system [5]. This value corresponds to only 15% of the technical potential of 4 GW that was previously mentioned. For 2022 the forecast installed power is 5.8 GW and the generation of surplus electricity is 30 TWh [2].

The biological conversion can be applied to biomass in its liquid state at low concentrations. This technology comprises biodigestion and alcoholic fermentation. It is also possible to obtain alcohol out of bagasse or wood after a hydrolysis process. The Brazilian program for the utilization of automotive alcohol 'PROALCOOL', in force from 1975 up to 1986, was considered to be the largest bioenergy program in the world. Today, all the gasoline in Brazil is mixed with alcohol at a concentration of 23%. Dual-fuel automobiles, which started to be commercialized in 2003, must give a new incentive to this program. Nowadays, 89.1% of the automobiles that leave the Brazilian factories are dual-fuel and it is expected that by the year of 2022 one third of the 30 million Brazilian automobiles will be dual-fuel. As a result of the Kyoto's Protocol and the high prices of oil, the alcohol production in Brazil must double and the exportation must jump from 1.9 billion liters to 10 billion within a period of 3 years [8]. 89 new ethanol distilleries projects are being carried out.

3.2. Paper and cellulose sector

The paper and cellulose sector, having more than 200 industrial units, produced 9 million tonnes of cellulose and 7.9 million tonnes of paper in 2003 [9]. The sector has more than 1.4 million hectares of planted forests where mainly eucalyptus and pine are grown with an average productivity, in 2002, of 50 and 33 $m^3\ ha^{-1}\ year^{-1}$, respectively. The sector is characterized by a high electric energy consumption, which in 2006 was 15.46 TWh [1]. It has excellent prospects for cogeneration out of renewable sources of energy (wood residue, bark and black liquor). Despite it all, if it were possible to use all the available fuel for cogeneration, it would be impossible the meet the electricity demand using available commercial technologies.

The cellulose industries have an installed capacity of 1280.0 MW [1]. The estimated technical potential of electricity generation in the sector for 2003 was 1740 MW [10]. The use of natural gas or gasified black liquor in gas turbines may be the path to achieve electric self-sustainability.

3.3. Agricultural residues

According to data provided by the Ministry of Agriculture, Livestock and Supply in the year of 2001 almost 100 million tonnes of grains, manioc and cotton were harvested, which equals to a little more than 130 million tonnes of residues (straw, stems and husks) [11]. Table 1 sums up the most important data regarding the volumes of crops, residues and their energy potential. This potential was calculated by considering the calorific value of the residues ranging about 15 $MJ\ kg^{-1}$, a conversion efficiency of 15% and a 50% possibility of recovering the residues (minimum potential). The maximum potential was calculated by considering a 20% conversion efficiency and a recoverable residue fraction of

Table 1
Data regarding the production of some agricultural products [11] and the availability of residues in Brazil (residue coefficient was taken from Nogueira and Lora, 2003)

Crop/residue	Production (10^6 tonnes)	Residue coefficient (CR)	Amount of residues (10^6 tonnes)	Minimum energy potential (MW)	Maximum energy potential (MW)
Corn/stalk + cob	41.4	1.0	41.4	1478.3	2759.5
Soybean/stems	37.7	1.40	52.7	1881.8	3512.8
Rice/straw + husk	11.4	1.7	19.6	700.7	1308.0
Wheat/straw	3.2	1.3	4.1	147.9	276.1
Cotton/branches	0.94	2.45	2.3	82.00	153.0
Manioc/stem + branches	22.5	0.8	18.0	641.5	1197.5
Coffee/husk	1.9	0.21	0.40	14.3	26.7
Total	119.0	–	138.5	4946.5	9233.6

70%. This way, we reached a total minimum potential of 4967.02 MW and a maximum one of 9271.77 MW.

Nowadays, only rice husks are used for electric energy generating purposes. In southern Brazil, where the greatest producers and the rice treating industries are concentrated, there are already several steam cycle thermal power plants, each with some MWs of capacity.

3.4. Wood industry residue

There are a few researches on the availability of wood residues in Brazil. One of them was carried out by IMAZON, a Brazilian Non-Governmental Organization, and it shows data regarding the years of 1997 and 1998. This study includes 95% of the timber companies of the Amazon region [10]. It was concluded that the amount of available residue lies about 7.6 million t y^{-1}. According to Macedo [6], this corresponds to a potential ranging between 430 and 860 MW.

3.5. Energy forests

It is hard to find data about the existing reforestation potential in Brazil and the productivity these energy forests would have, for there are many factors that influence the magnitude of the areas that could be planted. In the period between 1969 and 1994, 6.4 ha of eucalyptus and pine were planted in Brazil, out of which 90% were eucalyptus [13].

Today, it is possible to observe a deficit in the rhythm of reforestation that the country needs, so Brazil is importing timber for the furniture industry. This situation is known as 'forest blackout', which is an analogy with the energy crisis that took place in the country in 2001. CHESF (São Francisco Hydroelectric Company) carried out a study in 1993 that showed a reforestation potential using eucalyptus in the North-east region of 50 million hectares, which corresponds to 85 GW at a conversion efficiency of 20% [14]. On the other hand, Fearnside [15] forecast that in the year of 2050 there will be an available area in Brazil for forest activities of about 150 million hectares. Currently, eucalyptus from energy forests is mainly used by the paper and cellulose industry and for making charcoal for pig iron industry. One part of the planted eucalyptus will probably remain untouched in order to further the sequestration of significant amounts of atmospheric carbon. That is the reason why it would seem reasonable to assume that about 5% of the planted eucalyptus would have electricity generating purposes. This way there would be a potential that could go from 4000 to 8000 MW at a first approximation, considering a productivity reduction because of the increase in the cultivated area.

3.6. Oleaginous plants

The term 'oleaginous' includes a large number of vegetal oil producing plants with a widely varied chemical composition. Table 2 shows the characteristics and productivity of the oleaginous species that present the best interest in Brazil. We can highlight the African Palm or 'Dendê' because of its productivity, for it presents medium and long-term possibilities of replacing considerable amounts of petroleum derivatives. Da Costa [16] presents the results of a study that proposes the cultivation of palm oil in areas of the Amazon region that were deforested. For an area ranging from 2 to 3.2 million hectares the estimated oil production goes from 77.5 to 124×10^6 tonnes. Considering the producing states altogether, Goldemberg and Coelho [10] indicate a technical potential of electricity generation out of palm oil of 35.97 MW.

The Ministry of Mines and Energy instituted a program aiming at the production and rational use of biodiesel, which includes the consolidation of several transesterification pilot plants at universities and research centers and the replacement of a fraction of the fossil diesel used in the country for biodiesel within the next years. In 2008 an additional 2% is expected to be reached, with a Brazilian biodiesel market estimated as 800 million liters a year at the time. In 2012 the biodiesel fraction may be increased to 12% [17].

3.7. Total potential of electricity generation out of biofuels in Brazil

Table 3 summarizes the data about biofuel technical potential for electricity generation in different industrial and agricultural sectors in Brazil. The total potential, 13.8–27.8 MW, corresponds to 15–31% of the current installed power. These values constitute a primary approximation and must be refined based on future surveys.

Table 2
Characteristics of some oleaginous plants that present potential energy use [12]

Species	Origin of the oil	Content of oil (%)	Cycle for maximum efficiency	Harvesting months	Oil yield (t ha^{-1})
African Palm or 'Dendê' (*Elacis guineensis*)	Walnut	20	8 years	12	3.0–6.0
Avocado (*Persia americana*)	Fruit	7–35	7 years	12	1.3–5.0
Coconut (*Cocus numifera*)	Fruit	55–60	7 years	12	1.3–1.9
Babassu Palm or Macao coconut (*Orbignya martiana*)	Walnut	66	7 years	12	0.1–0.3
Sunflower (*Helianthus annus*)	Grain	38–48	Annual	3	0.5–1.9
Canola (*Brassica campestris*)	Grain	40–48	Annual	3	0.5–0.9
Castor-oil plant (*Ricinus communis*)	Grain	43–45	Annual	3	0.5–0.9
Peanuts (*Orachis hypogeae*)	Grain	40–43	Annual	3	0.6–0.8
Soy beans (*Glycine max*)	Grain	17	Annual	3	0.2–0.4
Cotton (*Gossypium hirsut*)	Grain	15	Annual	3	0.1–0.2

Table 3
Potential of electricity generation out of biofuels in Brazil

No.	Fuel sources	Minimum value (MW)	Maximum value (MW)	Current capacity (MW)
1	Sugar and alcohol sector[a]	3,500	8,000	1,400
2	Paper and cellulose sector	900	1,740	1,280
3	Agricultural residues	4,967	9,272	30 MW[b]
4	Timber industry residue	430	860	60 MW[c]
5	Energy forests	4,000	8,000	–
6	Oleaginous plants	36	–	–
	Total	13,833	27,872	2,770

[a] Potential referring to the electricity surplus that can be supplied to the grid.
[b] Thermal power plants that use rice husks as fuel. Four additional projects were presented recently with a whole power of 25.2 MW.
[c] Data about units implemented by the company (http://www.koblitz.com.br).

By looking at Table 5 it is possible to observe a considerable difference between the value of the total installed potential for electricity generation out of biomass indicated by ANEEL - National Agency for Electric Energy (4740 MW) and the value obtained by the authors (2680 MW). This is a consequence of several cogeneration plants that have already been built in the sugar/alcohol sector, which, at that moment, were not operating commercially. It is also important to consider that the data regarding generation out of wood residues are incomplete.

4. State-of-the-art of the technologies used for biomass - energy conversion

4.1. Available conversion technologies

Biomass needs to undergo several processes so that it can be widely used as a source of energy. These processes will transform its accumulated energy (carbon and hydrogen) into solid, liquid and gaseous fuels or into electricity. These kinds of energy have larger spectra and are easier to be used.

At first, there are three kinds of conversion processes: physical, thermo-chemical and biological. Fig. 4 displays the details of each process.

In order to analyze the potential technological option for the conversion of biomass into electricity it is convenient to classify the enterprises according to their electric power demand. Table 4 summarizes the information on available technologies and their technical and commercial maturity taking each power range into account.

From Table 4 we concluded that biomass energy technologies having the high and medium technological maturity and economic feasibility are the steam cycle, gasification with internal combustion and Stirling engine and biodiesel/internal combustion engines. For small power systems (5–200 kW) the situation is critical as they are not available technologies with high technogical maturity and economical feasibility.

4.2. Ongoing projects in Brazil

Presently in Brazil, a considerable amount of resources are being used to fund R&D projects in biomass energies technologies. Fig. 5 shows a diagram that allows us to explain how these researches are organized and funded.

Biomass R&D activities in Brazil are funded mainly ‘by the government through the Ministries of Science and Technology, Mines and Energy and Agriculture, livestock and food supply. The National Research Council - CNPq and Research and Project financing - FINEP are the main funding agencies of the Ministry of Science and Technology. A special fund CTENERG is devoted to energy related projects. Electric companies with the supervision of the National Electric Energy Agency (ANEEL) fund their research and development programs jointly with academic research groups and private consultancy firms. The origin of these funds is the 1% of the energy companies’ revenues, which they are forced, by law, to apply in R&D programs. The Brazilian oil company PETROBRAS through its research center CENPES financing line also funds research projects with the participation of academic groups in the field of renewable energy, specifically biomass energy (gasification, biodiesel, etc.).

The Ministry of Agriculture, Livestock and Food Supply though EMBRAPA (Brazilian Agriculture and Livestock Research Enterprise) created recently a research center—Embrapa Agroenergy and a consortium to joint efforts of

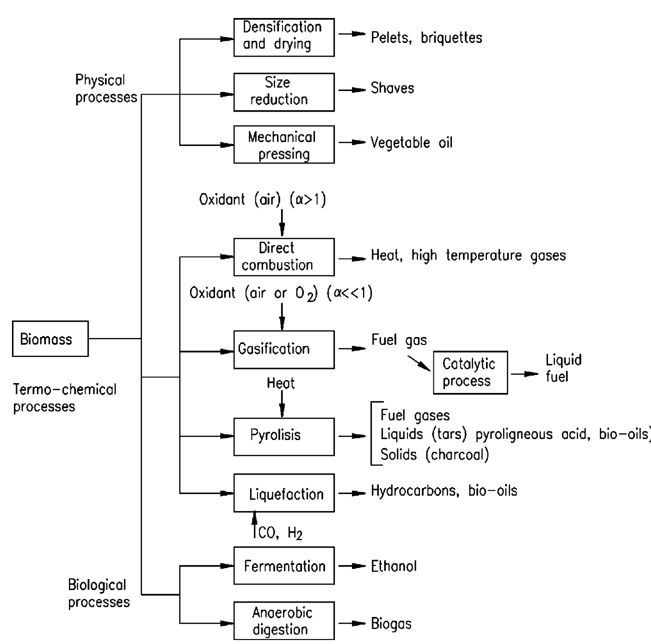


Fig. 4. Biomass energy conversion routes.

Table 4
Available technologies for electricity generation out of biomass for different power ranges

Power range (kW)	Technology[a]	Technological maturity			Commercial feasibility			Comments
		H	M	L	H	M	L	
5–200 kW	Combustion/steam cycle	X				X		High cost and low efficiency conversion
	Gasification/ICE		X			X		Few commercial options and successful projects
	Gasification/GMT			X			X	Ongoing research projects
	Gasification/SE		X				X	Ongoing research projects
	Combustion/SE	X				X		Commercial/demonstration units
	Gasification/FC			X			X	Ongoing research projects
	Biodiesel/ICE		X			X		Initial commercialization. Biodiesel quality problems
200–1000	Combustion/steam cycle	X			X			High cost and low efficiency conversion
	Gasification/ICE	X				X		Some demonstrative/commercial units
	Gasification/FC			X			X	Mathematical modeling
>1000	Combustion/Steam cycle	X			X			Demands low cost fuels
	ORC—Organic Rankine Cycle	X				X		High costs
	Gasification/GT (BIG/GT technology)		X				X	Some demonstrative units. High efficiency
	Gasification/FC			X			X	Mathematical modeling and EU project in initial stage

[a] ICE—internal combustion engine, GMT—gas micro-turbine, SE—Stirling engine, FC—fuel cell and GT—gas turbine.

entities offering and using biomass energy technologies and products (Fig. 5).

A special program has been developed to encourage the use of alternative sources of energy (PROINFA) and another program aims at taking electric power to the whole country one (Light for Everyone). The latter has a special fund for the development of advanced generation technologies for isolated communities based on renewable energy. Below both these programs are discussed in more details.

Research projects are properly carried out in major academic institutions all over the country such as UNIFEI/NEST; São Paulo State University (USP)/IPT; Campinas State University UNICAMP/FEM/FEAGRI/NIPE; Federal University of Pará (UFPA)/EBMA; University of Fortaleza (UNIFOR)/TC; Federal University of Amazonian (UFAM)/CDEAM; Federal University of Paraiba (UFPB)/LES, Federal University of Bahia UFBA/LEN and others.

There are also some organizations aimed at joining and coordinating the efforts of all these research groups such as the

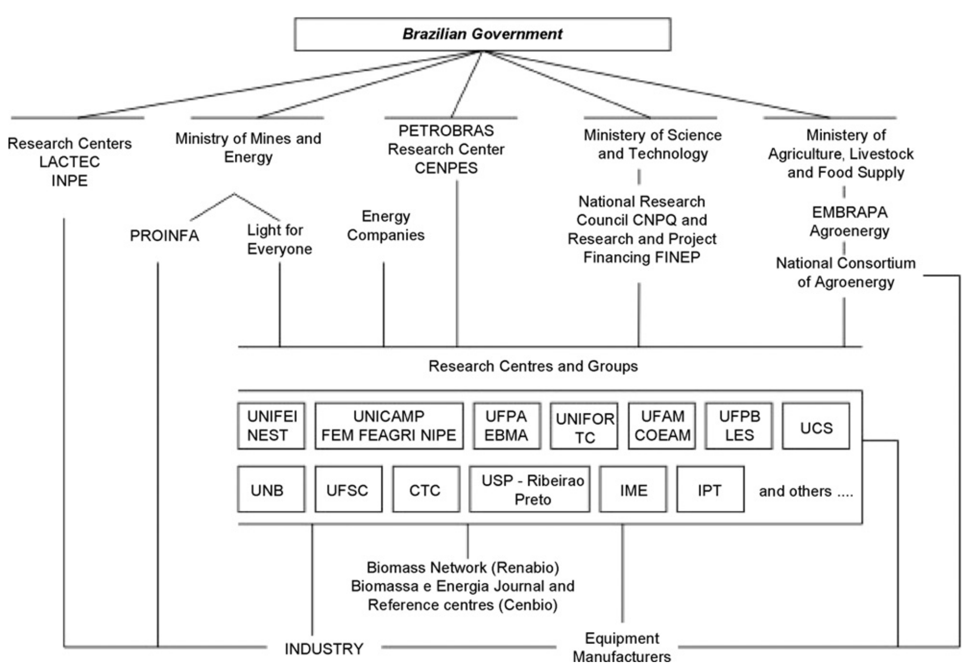


Fig. 5. Diagram of the organization links and funding of biomass R&D activities in Brazil.

Fig. 6. Picture of the diesel engine that use ''in-natura'' oil of African palm (PROVEGAM project) [18].

Biomass Reference Center CENBIO and the Biomass Network RENABIO. The latter publishes the scientific journal ''Biomassa e energia'' in Portuguese (Biomass and Energy). A growing interaction is being developed between academic groups, equipment manufacturers and biomass using industries.

An attempt is being done to support the actions of thematic networks, grouping different research groups and companies such as the Combustion and the Renewable Energy Networks and RECOMBIO devoted to Biodiesel. The main problem now is the introduction of the research results in productive and economic activities.

A few of the ongoing biomass projects in the country are described below. It is far from our intention to present a full list as the length of the paper does not allow for that. Finally, NEST research activities are described in more details, considering their widespreading and practical characteristics.

4.3. PROINFA—a program that encourages the use of alternative sources of energy

Aiming at encouraging the implementation of projects and the use of alternative sources of energy, the Brazilian government launched PROINFA, which is in force through Law no. 10,438, April 26th 2002 and revised by Law no. 10,762, November 11th 2003. PROINFA's objective is the diversification of the Brazilian energy matrix and the search for regional solutions through the use of renewable sources of energy. The goal of the program is to implement a capacity of 3300 MW in generating installations which are forecast to start operating before December 30th 2006. The federal owned company Eletrobrás assures the purchase of the electricity produced by the authorized entrepreneurs over a period of 20 years. The total investment in PROINFA projects is estimated to range about 3.6 billion dollars.

PROINFA's first selection process for biomass projects resulted in the selection of projects comprising 327 MW and the second selection process reached 1080 MW. A total power of 1100 kW for biomass generation projects must be authorized.

The program 'Light for Everyone' intends to accomplish the universalization of electric energy supply until the year of 2008. Within this period, electric power must reach the houses of 12 million Brazilians at a cost of 3.3 thousands million dollars. This program will be carried out through a partnership between electricity companies and state governments. Three technological alternatives are considered: the extension of the grid, decentralized generating systems with isolated distribution grids, and individual generating systems. Currently, some isolated communities in the Amazon region use diesel generators at an average generating cost ranging between 200 and 285 US\$ MW h^{-1}, whereas in the interconnected system the generating cost is around 30 US\$ MW h^{-1}.

4.4. Generation project using diesel engines and 'in-natura' vegetal oil - PROVEGAM

This project is being conducted by the National Reference Center for Biomass—CENBIO and it is an alternative to supply electricity to isolated communities using the ''in-natura'' oil coming from 'Dendê' (African palm) as fuel [18]. PROVEGAM was implemented in Vila Solidão, a community that belongs to the town of Moju in the state of Pará. This community has 700 inhabitants. Before the project, the community had an old diesel engine, and the situation became worse because of diesel high prices.

The project, then, used a 100 kW (power) 6-lined-cylinder T model diesel engine (Fig. 6). It was cooled by a radiator and had a mechanical injection system. The engine is coupled to a triphase generator with a voltage regulator. In order to make the direct use of the oil in the engine possible a German-manufactured adapting module was purchased, and its main function is to pre-heat the fuel.

Shortly after that a considerable loss of power was observed in the engine and there were also obstructions due to the solidification of the densest part of the vegetal oil at certain points of the equipment, even with the use of diesel when it was started and shut down. A new conversing module for the engine using vegetal oil was then developed (Fig. 7). During the engine operation the temperature of the palm oil at the pre-heating tank outlet was kept between 70 and 75 °C. With this new conversing module the diesel generator presented optimum performance and power.

After operating for 500 h the injectors presented a deposit formation slightly more intense than what was presented by the operation with diesel over the same period of time. After 750 h, the injectors, the engine cylinder heads and the injection pump were replaced. The other parts of the engine presented good conditions to carry on running with vegetal oil.

The availability of good quality energy in a continuous way made it possible for the inhabitants of Vila Solidão to invest in machines to process assai (an Amazonian region fruit), one of the main sources of nourishment in the rural communities of the state of Pará, which also has a huge commercialization potential.

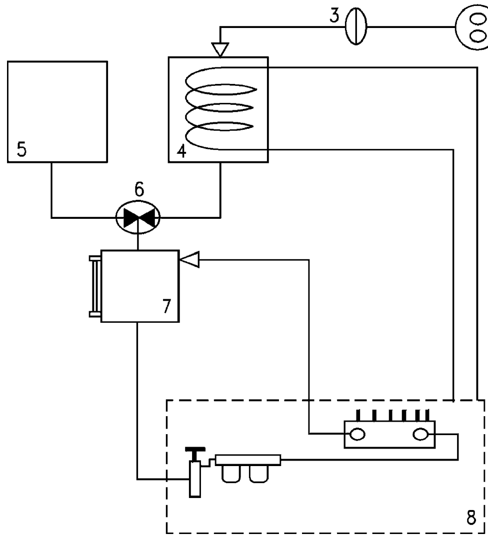


Fig. 7. Scheme of the different elements of the diesel engine conversing module for the use of "in-natura" vegetal oil (PROVEGAM Project). 1, Drum ('Dendê' oil); 2, pump; 3, filter; 4, tank ('Dendê' oil); 5, tank (diesel); 6, three-way valve; 7, mixture reservoir; 8, diesel engine [18].

4.5. Project with biomass gasification - GASEIFAMAZ

The GASEIFAMAZ project "Comparison between the existing technologies for biomass gasification" is a partnership between CENBIO (National Reference Center for Biomass), BUN (Biomass Users Network of Brazil), IPT (Institute of Technological Research of the state of São Paulo) and UA (University of Amazonas) [19]. The main objective of the project is to assess the Indian technology of small-scaled fixed bed gasification aiming at supplying electric energy in a sustainable way to isolated communities located in the Amazon region. This way, a 20 kW gasification system was imported from the Indian Institute of Technology. During the tests at IPT an average calorific value over 5.7 MJ/N m^3 (PCS) was obtained for a biomass consumption of 18 kg h^{-1}.

This gasification system was installed in a community called Aquidabam, which is part of the town of Manacaparú in the state of Amazonas. The community has 180 houses and 700 inhabitants. One of its main local products is 'cupuaçu', a fruit found in the Amazon region, which is sold 'in-natura' with a low aggregated value. The installation of the gasification system is expected to allow the formation of a local agro-industry for the commercialization of 'cupuaçu' pulp, which will allow a rise in the community's income and, consequently, a rise in its life quality (Fig. 8).

4.6. Projects using steam cycle

4.6.1. Thermal power plant at lajes (UCLA)

The UCLA thermal power plant (Fig. 9) has an installed power of 28 MW with 25 t h^{-1} steam generation in the boiler. It uses wood residues as fuel. The city of Lages is an important timber industrial center and the disposal of the wood processing residues was causing negative environmental impacts. The main technical parameters of this plant are presented in Table 5.

4.6.2. Piratini thermal power plant

This plant was designed and built by the company Koblitz, which is a leader in Brazil when it comes to biomass generating and cogenerating enterprises. The plant is located in the southern part of the city of Piratiní, state of Rio Grande do Sul, and it has been operating since 2002. The plant has an installed power of 10 MW and consumes about 142 thousand tonnes of wood residues annually to produce approximately 71 thousand MW h $year^{-1}$. The investment cost was US$ 8.7 million [20]. Fig. 10 displays photos showing an overview of the plant and the boiler.

4.7. Landfill biogas

This project is being carried out by CENBIO and SABESP (Water Company of the state of São Paulo) at the Effluent Treatment Station in the city of Baruerí, São Paulo [21]. A 30 kW CAPSTONE gas micro-turbine was installed. This micro-turbine runs with the biogas that comes from the anaerobic biodigestion of household residual water. The project began in December 2002 and its objective is to assess the possibility of using micro-turbines at small capacity plants

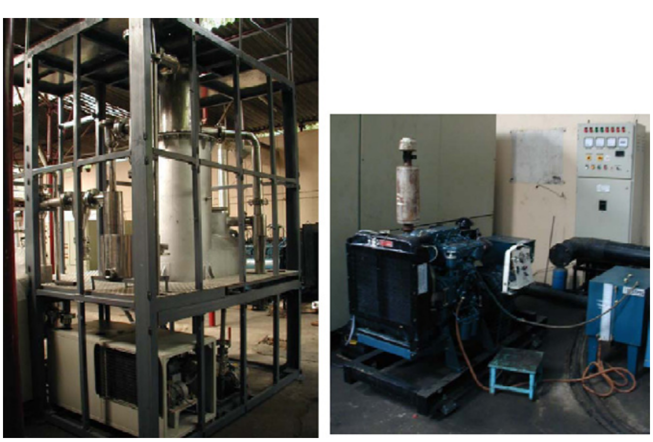


Fig. 8. 20 kW gasifier/diesel engine system during the tests at IPT, Brazil (GASEIFAMAZ project) [19].

Fig. 9. View of the UCLA biomass thermal power plant, operated by Tractebel Energia, located in Lages, state of Santa Catarina.

Table 5
UCLA main technical parameters

Parameter	Value
Electric power (MW)	28
Efficiency (%)	21
Investment cost (R$, 10^6)	85
Steam parameters	
Temperature (°C)	485
Pressure (MPa)	6.0
Steam flow ($t\,h^{-1}$)	120
Boiler efficiency (%)	85
Steam generation index (tonnes of steam per tonne of biomass burned)	2.21
Steam specific consumption (tonnes $MW\,t^{-1}$)	3.85

where the treatment of effluents can be performed. In addition, a comparison between the emissions released from reciprocating engines and micro-turbines is also carried out. Table 6 presents the data about the composition, calorific value and relative density of the biogas used in the tests. It is possible to notice that the calorific value of the biogas has approximately half of the value corresponding to natural gas, but it is 4–5 times greater than the value of the gas that comes from biomass thermo-chemical gasification (Figs. 11–14).

The contaminants present in the biogas affect the performance of the engine as it will be described:

- Moisture: besides reducing the biogas calorific value, it may compromise the operation of the internal parts of the micro-turbine. In order to reduce the gas moisture, coalescing filters and cooled dryers were used before and after the compressor;
- H_2S: it may damage the internal parts of the dryer, of the compressor and of the turbine because of its corrosive character. A coal filter was used to remove the H_2S. The H_2S dissolved in water was removed by the coalescing filters and dryers. Most of the anaerobic digesters produce a gas with 0.3–2.0% of H_2S;
- The presence of air inside the tubes reduces the gas calorific value;
- Siloxane: its presence was detected at concentrations of some ppb's in the biogas. This is a compound of silicide, derived from cosmetics, which may cause long-term problems to the rotors of the micro-turbines (formation of silicide particles at high temperatures).

Table 6
Composition and characteristics of the biogas supplied to the micro-turbine

Parameter	Value
Methane (CH_4) (%)	66.5
Carbon dioxide (CO_2) (%)	30.5
Oxygen (O_2) + Nitrogen (N_2) (%)	0.5
Moisture (H_2O) (%)	2.5
Hydrogen sulfide (H_2S) (%)	0.01%
LHV ($MJ\,m^{-3}$)	22.19
Relative density	0.86 a 15 °C, 101.3 kPa

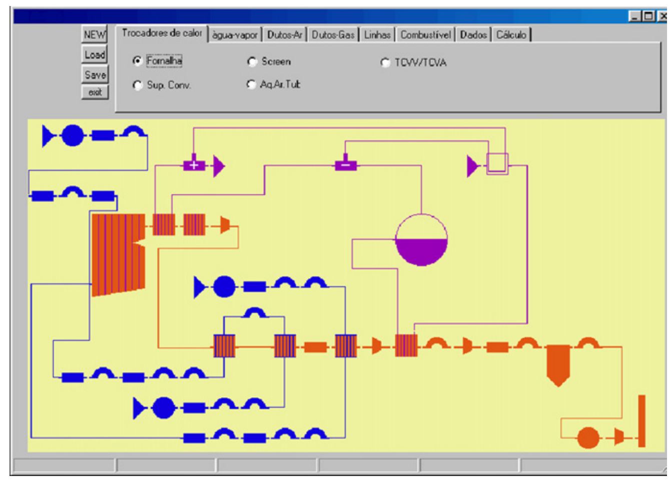


Fig. 11. Assembly of the scheme of a bagasse boiler on the SBC input screen.

The results of the readings of the exhaust gases composition show that the concentrations of NO_x were approximately 1 ppm, which is far lower than the value corresponding to internal combustion engines that operate with diesel.

5. Bioenergy studies at NEST—excellence group in thermal power and distributed generation

NEST was created in March 7th, 1998 at the Federal University of Itajubá and it is part of the Mechanical Engineering Institute. Currently NEST is formed by more then 35 researchers where 7 are PhD, 7 masters and 5 professors. The principal lines of research are: power

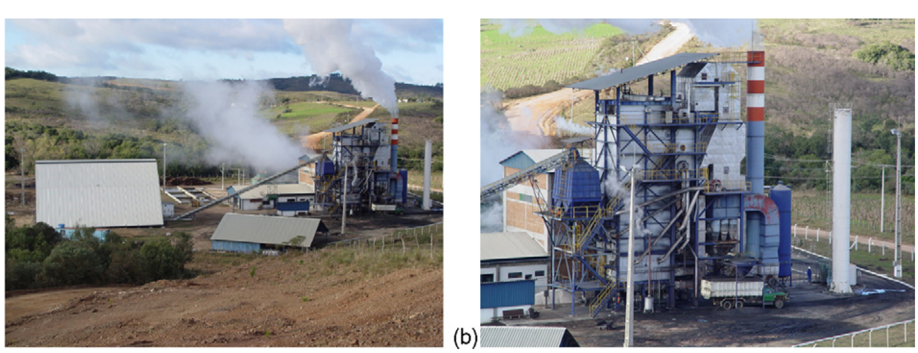
(a)  (b)

Fig. 10. Photos of Piratini thermal power plant operated by Koblitz. (a) Thermal power plant overview. (b) Steam boiler.

Fig. 12. Firewood boiler used for driving a 400 W Stirling engine.

generation and cogeneration, gas and steam turbines, advanced technologies for distributed generation (internal combustion engines, micro-turbines, Stirling engines and fuel cells), energetic use of biomass (gasification and combustion), biodigestion (landfill and vinasse), refrigeration and air conditioning, thermal process modeling and diagnostics, life-cycle analysis and environmental aspects of energy use.

NEST has 6 laboratories: gas turbine and biomass gasification, steam and diesel thermal systems, advances systems for distributed generation, refrigeration and air conditioning, simulation of thermal systems and process and training simulator for thermal power plant operators. The Group has been working in R&D with incentives coming from the government and private institution such as CEMIG, FINEP, CNPq, CENPES, Bandeirante, Tractebel Energia, Petrobras and CPFL. NEST's scientific production includes 8 books about

Fig. 13. View of UNIFEI's biomass gasifier with biomass feeding and gas cleaning systems.

Fig. 14. SOLO Stirling engines installed in UNIFEI's laboratories.

energy issues and several papers that have been published in important journals and presented in meetings and published in their proceedings.

The results obtained in the main research lines are briefly presented below:

(a) Combustion
- Adjustment of the combustion, measurements of the concentration of gaseous contaminants (NO_x and particles) present in biomass steam boilers and it control;

Development of the SBC Software: it carries out the thermal and aerodynamic calculation of steam boilers that burn sugar cane bagasse. The calculation methodology corresponds to the one that was proposed by the Russian normative method for the thermal and aerodynamic calculations of steam boilers. The scheme formed by one boiler, air and gas ducts, fans, soot blowers and a chimney can be assembled from different elements, surfaces and ducts by using a friendly interface;
- Assessment of the exhaust gases optimum temperature in bagasse boilers: four different constructive modification options were considered for a modern suspension burning boiler. Also, different scenarios for the bagasse prices and for electricity surplus commercialization were taken into account. The value of the exhaust gas temperature obtained from the analysis that uses the electricity surplus commercialization prices as a reference is approximately 120–130 °C [22];

Emission and control of atmospheric pollutants released from bagasse boilers and it dispersion [23].
- Design, construction and tests of furnace/Stirling engines systems for the operation in isolated regions, based on a Cagiva motocycle crank case [24,25].

(b) Gasification
- Study of the gasification process and performance of the fluidized bed and cross-flow gasifiers [26];
- Tests of a 10 kW gasifier/ICE system using a gasoline engine and recently tests of a two stage gasifier manufactured by CEMIG;

- Experimental assessment of the operation of a 30 kWe micro-turbine using biomass gasification gas/natural gas mixtures; assessment of the necessary modifications in the turbine for the operation with biomass gasification gas only;
- Assessment of Stirling engine/biomass gasification systems;
- Mathematical modeling and experimental assessment of a 5 kWe Solid Oxide Fuel Cell (SOFC) and of hybrid systems with micro-turbines; the evaluation of the possibility and the requirements for coupling the SOFC to a biomass gasifier;

(c) Biodiesel
- Palm-oil biodiesel life-cycle energy balance and tests on the burning of different diesel/biodiesel mixtures and pure biodiesel in gas micro-turbines [27,28].

(d) Biogas
- Theoretical–experimental study on the biodigestion and combustion technologies for the treatment of the stillage obtained as a residue from alcohol production. LCA of different ethanol stillage treatment and disposal methods.
- Evaluation of the potential for biogas production and electricity generation from different residues;

(e) Cogeneration and carbon credits
- Development of a software for prime-movers selection and the assessment of the performance and economic feasibility of cogeneration systems [29–31];
- Assessment of the economic impact of the commercialization of carbon credits on electricity cogenerating and generating projects out of biomass;
- Optimization of productive diversification projects in the sugar and alcohol industry.

6. Conclusions

- Brazil is one of the countries in the world that has the most advanced programs aiming at the implementation of the use of biomass energy, particularly 'modern biomass';
- The demonstrative and commercial projects that are being implemented in Brazil must offer important information for overcoming the technical and commercial barriers that make the extensive implementation of bioenergy difficult;
- Biomass gasification has a wide scope of application and must constitute the basis of the dissemination of 'modern biomass' use. Efforts and resources are necessary so that this technology can have its commercial phase initiated;
- The ongoing projects at NEST have embraced almost all the spectra of bioenergy potential applications with advanced technologies. The creation of a center focusing on the training in advanced bioenergy technologies, and also their development, using NEST's laboratory infrastructure is, being, proposed.

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